Determining the Temporal and Spatial Variability of Biomass Productivity in a Pilot-scale Algal Resource Recovery Unit Treating Agricultural Wastewater

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Abstract

Idaho dairy cows produce an estimated 3 million tons of dry manure annually; each ton contains 4.5 kg of nitrogen (N) and 0.82 kg of phosphorous (P). Excess application of manure as crop fertilizer can contaminate aquifers and surface water due to leeching of N and P. We constructed three replicate Algal Resource Recovery Units (ARRU) at the University of Idaho dairy facility in Moscow, ID to test their utility to manage nutrients and produce algal biomass as a secondary commodity. Each ARRU was inoculated with a mixture of algal cultures consisting of *Chlorella vulgaris*, *Scenedesmus obliquus*, and *Synechococcus leopoliensis*, as well as a consortium of algae species obtained from the Boise River and received one of 3 treatments A) lagoon waste water; B) a mixture of 90% PHAE and 10% anaerobic digester effluent (ADE); or C) 100% effluent from a polyhydroxyalkanoate reactor effluent (PHAE). Daily Nitrogen and Phosphorus removal were 83.6%, 82%, and 83.7% N removal and 86.2%, 78.7%, and 68.7% P removal for treatments A, B, and C, respectively. Biomass productivity was 11.8,19.5, and 17.6 g/m^2/day for each 5 day composite treatment and 6.3, 12.9, and 11.6 g/m^2/day for each 6 day composite treatment. Algal growth and nutrient removal rates are being evaluated for nutrient management and as secondary commodities.

Objectives

- Design and continuously operate a pilot scale ARRU for up to 6 months that is capable of treating effluent from 1) Dairy Lagoon water, 2) a mixture of PHA and AD effluent , and 3) PHA reactor effluent (Effluent process shown in Figure 1).
- Determine feasibility of large scale nutrient removal from dairy waste using an ARRU.
  - Analyze phosphorous and nitrogen removal over time and across various different wastewater streams.
- Measure temporal stability in algal productivity within each treatment.
- Analyze spatial variation of algal biomass production within each replicate ARRU and across treatments.

Methods

Construction:

- Three ARRUs (one for each treatment) were constructed at the University of Idaho dairy utilizing a white 500 micron nylon mesh substrate with a 10.7 m^2 harvestable area.
- Each ARRU was inoculated with a mixture of algal cultures consisting of *Chlorella vulgaris*, *Scenedesmus obliquus*, and *Synechococcus leopoliensis,* as well as a consortium of algae species obtained and grown from the Boise River.
- Each ARRU received a treatment of lagoon waste water, 10% ADE 90% PHAE, or 100% PHAE. Temperature, pH, and photosynthetically active radiation (PAR) values are being monitored throughout each ARRU.

Sampling:

- Each ARRU was allowed to grow for either 5 or 6 days at a time. 5 and 6 day composite samples were taken from each ARRU using a stratified random sampling design.
- Biomass was collected using a shop-vac apparatus that accumulated biomass separately for each treatment into a container for temporal biomass productivity measurements.
- Spatial biomass productivity measurements were sampled in the same manner with the exception that each sampling segment was stored individually.
- Samples obtained using the shop-vac apparatus were sub sampled and preserved for carb, protein, and lipid content analysis as well as cell counts and AFDW measurements.

Nutrient Analysis:

- Total dissolved N, and dissolved NO_3^-, soluble reactive P, and total P were measured using standard colorimetric assays as per Hach method 10020, 8048, and 8190.

Algal Biomass Productivity Measurements:

- Algal biomass was measured by estimating Ash Free Dry Weight (AFDW) using standard methods. Briefly, each sample was weighed wet, dried for 2 hours, the total dry weight determined, and then combusted at 500°C for 30 minutes to determine ash content of the biomass. AFDW = total dry weight – ash content.
- Biomass productivity for each ARRU raceway was determined by calculating the net AFDW produced per m^2 per day.

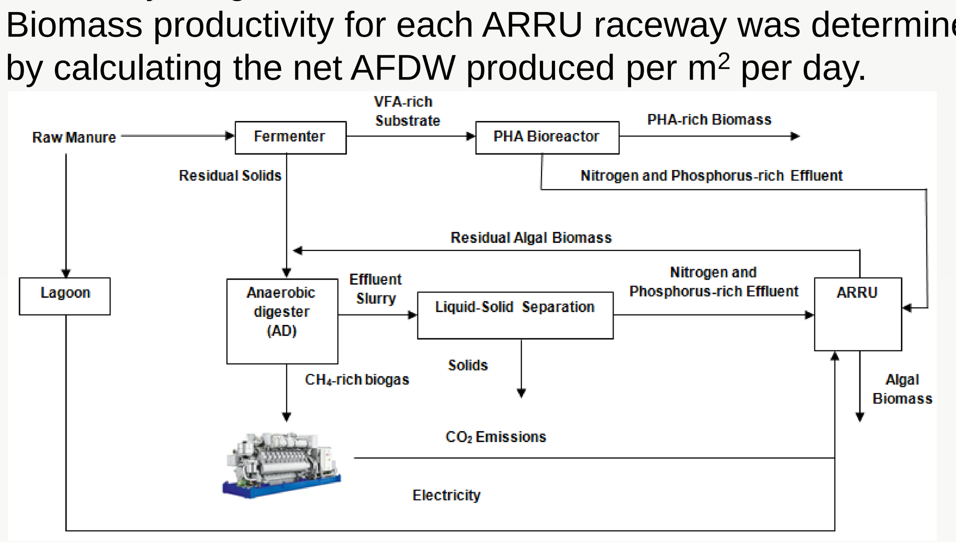

Figure 1. Diagram of dairy wastewater operation for nutrient management and production of algal based economic commodities.

Acknowledgements

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Results

Design:

Figure 2. Each ARRU above has a 10.7 m^2 harvestable area. A 500 micron white nylon mesh was utilized as an algal substrate. Treatment media flows down each ARRU from the tipping bucket at the ARRU head to the settling tanks at each ARRU tail end. The media is pumped back into the tipping bucket where it will once again be dispersed throughout each ARRU after a fixed time period.

Temporal Variability:

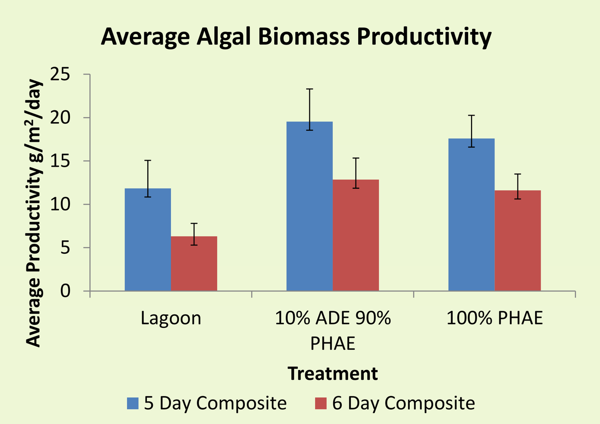

Figure 3. Average algal biomass productivity amongst each treatment averaged over an approximate 75 day operation window. 5 and 6 day composite samples taken from each ARRU were composed of all 5 and 6 day old algal biomass, respectively. Bars = mean values (n = total sample number/treatment/type of composite), error bars = standard deviation

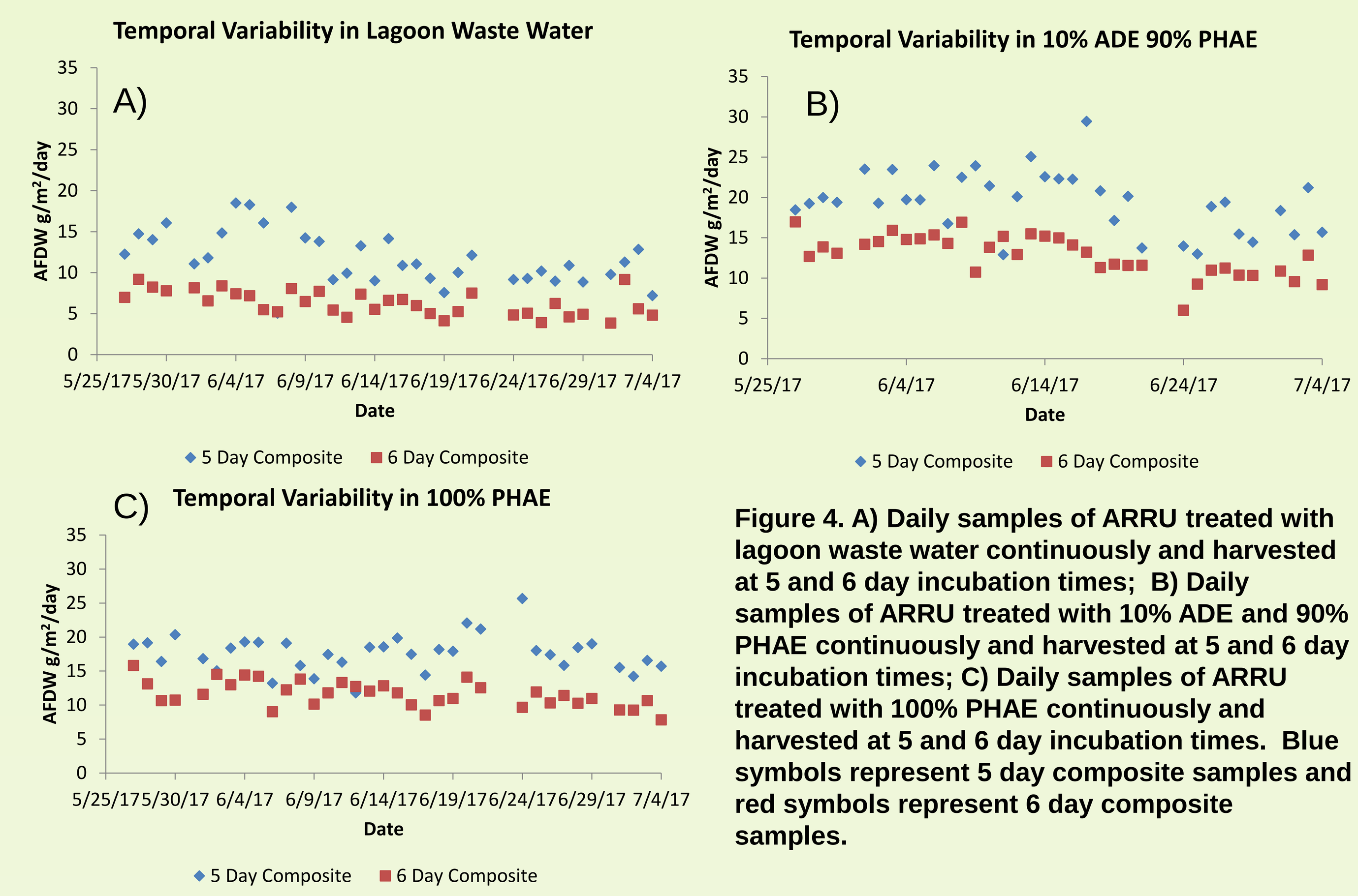

Figure 4. A) Daily samples of ARRU treated with lagoon waste water continuously and harvested at 5 and 6 day incubation times; B) Daily samples of ARRU treated with 10% ADE and 90% PHAE continuously and harvested at 5 and 6 day incubation times; C) Daily samples of ARRU treated with 100% PHAE continuously and harvested at 5 and 6 day incubation times. Blue symbols represent 5 day composite samples and red symbols represent 6 day composite samples.

Spatial Variability:

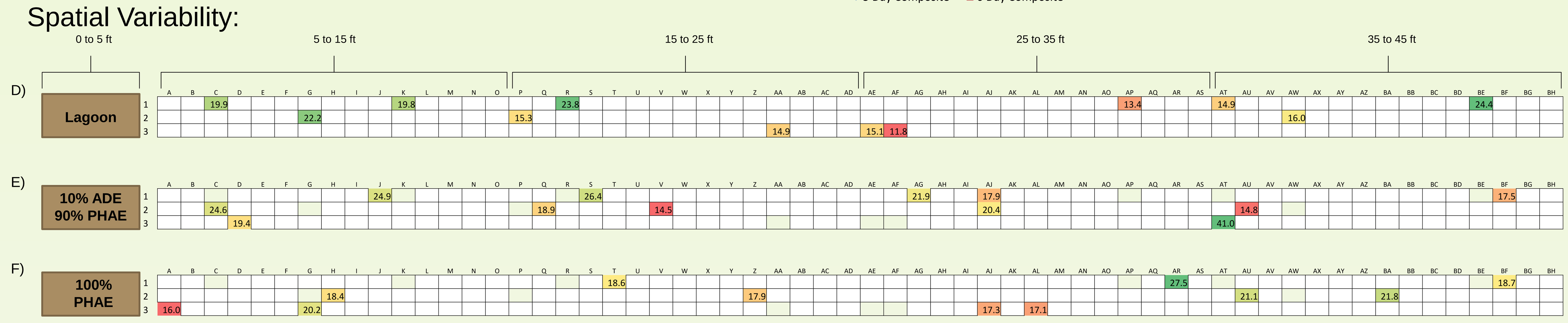

Figure 5. Spatial variation of algal productivity for D) lagoon, E) 10% ADE 90% PHAE, and F) 100% PHAE treatments analyzed from 6/11/17 samples. Color ranges from green to red, with green representing the highest productivity and red representing the lowest productivity. Each segment was sampled after approximately 6 days of algal growth.

Nutrient Removal:

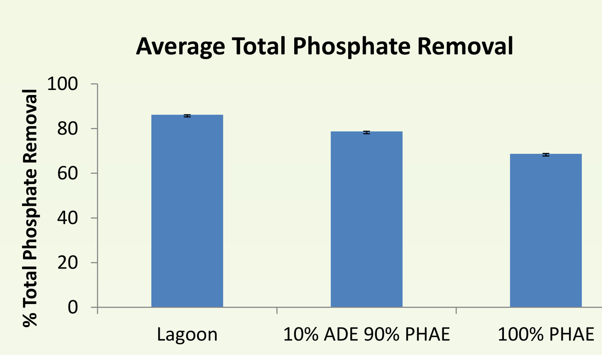

Figure 6. Average percent total phosphate removal for each treatment averaged over an approximate 30 day operation window. Bars = mean values (n = total measurements/treatment/30 days), error bars = standard deviation.

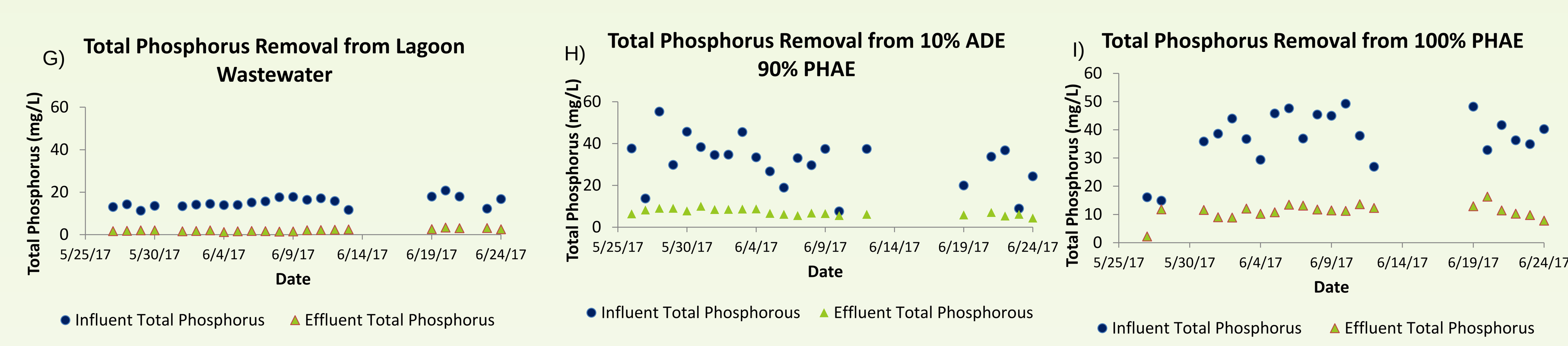

Figure 7. Total Phosphorous removed from G) lagoon waste water, H) 10% ADE 90% PHAE, and I) 100% PHAE ARRU treatments over an approximate 30 day operational window. Total phosphorous was measured using Hach method 8190. Purple circles represent influent total phosphorous and green triangles represent effluent total phosphorous. Influent is treatment going into each ARRU, effluent is treatment that has been in the ARRU for 24 hours.

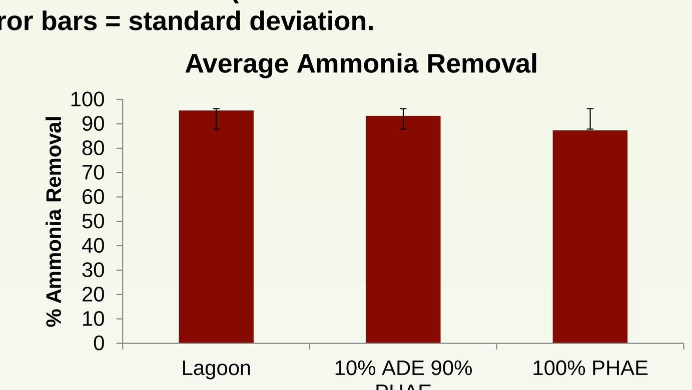

Figure 8. Average percent ammonia removal for each treatment averaged over an approximate 30 day operation window. Bars = mean values (n = total measurements/treatment/30 days), error bars = standard deviation.

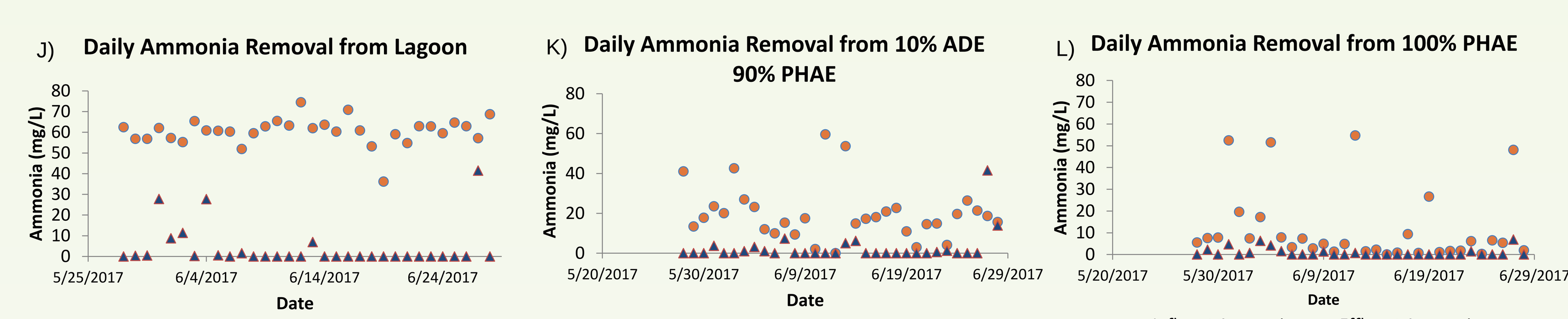

Figure 9. Total ammonia removed from J) lagoon waste water, K) 10% ADE 90% PHAE, and L) 100% PHAE ARRU treatments over an approximate 30 day operational window. Ammonia was measured using Hach method 8190. Orange circles represent influent ammonia and blue triangles represent effluent ammonia. Influent is treatment going into each ARRU, effluent is treatment that has been in the ARRU for 24 hours.

Discussion

Temporal Biomass Productivity:

- Average algal biomass productivity was 11.8,19.5, and 17.6 g/m^2/day for the 5 day composite lagoon wastewater, 10% ADE 90% PHAE mixture, and 100% PHAE treatments respectively and 6.3, 12.9, and 11.6 g/m^2/day for the 6 day composite lagoon wastewater, 10% ADE 90% PHAE mixture, and 100% PHAE treatments respectively
- Variation in biomass productivity between treatments may be due to a number of factors including but not limited to nutrient content, light attenuation, and competition from other microorganisms for resources.

Spatial Biomass Productivity:

- Initial analysis of the spatial data shows variation in algal biomass productivity amongst segments within each ARRU.
- Variation in algal biomass productivity amongst sampling segments within each ARRU may be attributed to differences in nutrient availability and temperature throughout different regions of each ARRU. On-going analysis is assessing which of these factors controls spatial variability.

Total Phosphorous Removal:

- Average total phosphorous removal across treatments was 86.2, 78.7, and 68.7 percent for the lagoon wastewater, 10% ADE 90% PHAE mixture, and 100% PHAE treatments respectively.
- Variation in phosphorous removal can be due to a number of factors including types of phosphorus within each treatment as well as microbial species present to break down various types of phosphorus.

Nitrogen Removal:

- Average ammonia removal across treatments was 95.5, 93.3, and 87.34 percent for the lagoon wastewater, 10% ADE 90% PHAE mixture, and 100% PHAE treatments respectively.
- On-going work is determining NO_3^- and Total N removal rates.

Algal Biomass Quality:

- On-going work is determining algal biomass quality (i.e. carb:protein:lipid content) to evaluate the use of algal biomass as an economic commodity in the form of bio-crude or cattle feed.

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